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NETWORK DECOMPOSITION AND ALTERNATIVE LINK SCREENING OF THE CHICAGO RAPID TRANSIT NETWORK

TR-76-10

Technical Report

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THE CHICAGO RAPID TRANSIT NETWORK

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By
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Note to the Reader

This report is an abridged version of a working paper written as a part of a rail system investment plan being developed for Northeastern Illinois. The Study of New and Replacement Rail Transit Alternatives (SONARRTA) will provide a long-range framework (to the year 2000) within which proposed rapid transit and commuter rail projects can be evaluated and programmed.

Due to the expensive nature of constructing new and replacement facilities, it is clear that not all potential projects can be built. Trade-offs must be made among maintaining and renewing segments of the rail system, replacing current segments, and adding new lines. The study conclusions will establish the extent to which the rail system can be improved given different assumed availabilities of federal operating and capital funds. Proposed lines that show the greatest benefit in terms of user savings, accessibility, ridership, and environmental impact will be recommended for detailed corridor-level analysis.

I. INTRODUCTION AND PURPOSE

At the present time, a large number of rapid and commuter rail lines* have been included in SONARRTA. Due to the interdependence of benefits between lines** (henceforth denoted as line interdependence), it is impossible to find the optimum rail network by simply evaluating each line individually, and then combining the preferred lines to form the network.

The theoretically correct method of treating this problem involves defining an extremely large number of alternatives which consist of all possible combinations of the proposed links. However, since approximately 200 links have been proposed, this would entail evaluating some 2^{200}, or more than a trillion, alternatives. In other words, the theoretically correct evaluation method is utterly impossible to use.

An evaluation method which addresses this problem has been formulated. It is envisioned as a three stage process involving corridor-specific sketch planning, macro system-wide planning, and micro corridor planning. SONARRTA itself includes the first two phases, and its results pinpoint corridors which require the micro planning.

Corridor specific sketch planning involves two distinct parts: network decomposition and line screening. Network decomposition involves the classification of lines into various types and the grouping of lines into semiautonomous corridors. Line screening involves the application of a demand per unit cost criterion to the lines within a corridor so as to choose the optimal line within the corridor. These optimal lines, along with the do-nothing alternatives and the constant lines assumed to be in existence till the horizon year, are then input into the macro, system-wide network planning phase as alternatives for optimization. The two criterion components, demand and cost, are defined so as to include the important factors relevant to a specific corridor, and are sensitive to corridor level impacts.

Macro system-wide planning involves the application of a mathematical programming model which maximizes total regional benefits within budget constraints, so as to determine the optimum target year network. The regional benefit is defined so as to include a wide range of impacts, and is developed and applied on a regional scale, so that it measures net changes in regional benefits. Transfer payments or redistribution of benefits within the region are not included.

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*Lines are defined as a set of connected links. It is possible that a link may belong to more than one line.

**For example, the user savings associated with the simultaneous construction of radial and crosstown rapid transit lines would be greater than the sum of the individual savings provided by the radial and crosstown lines.

The results of the macro regional planning include an evaluation of all corridor optimal lines to determine an optimal network. These results will be interpreted in broad terms, so as to provide general guidance in terms of the relative priorities of maintaining and rehabilitating the existing system, improving the existing system, and constructing new lines; to suggest actions (build/no-build decisions for lines) on a corridor level; and to pinpoint relative priorities between corridors.

For those network changes which are considered high-priority, detailed corridor studies will be undertaken. These studies will be based largely on the first two evaluation phases, but will be more inclusive, and will be done at a micro-analytical level. At this level, the distribution of benefits within the region as they apply to the specific corridor are explicitly included in the analysis.

This overall evaluation method, which is basically a micro-macro-micro process, can hopefully address many of the deficiencies inherent in macro system planning, as well as the problems of detailed corridor planning without having an overall regional plan.

This report will focus on the first phase of this technique, the corridor-specific sketch planning as it relates to rapid transit lines. Because the proposed changes to the commuter rail system are less complex, it is not necessary to apply the sketch planning phase, and the proposed lines can be directly input into the macro system-wide phase.

II. SKETCH PLANNING METHOD

A. Network Decomposition

1. Line Classification

The first part of network decomposition is classifying rapid transit lines into two types: constant and variable. Constant lines are those selected existing lines which are assumed to be in existence till the Year 2000; and include lines which were either constructed recently or do not require major capital maintenance over the planning horizon. Variable lines include existing lines which may be either renovated (replaced) or entirely removed, and proposed new lines. Map One shows the various lines.

2. Corridor Definition

The second part of network decomposition involves grouping the variable lines into semi-autonomous corridors. A semi-autonomous corridor is defined as a set of lines which are similarily impacted by lines in other corridors. While the existence/non-existence of lines in other corridors does have somewhat of an impact on benefits of lines within a corridor, this impact is fairly equal for all lines within the corridor. Thus, lines within individual corridors can be evaluated independently of the existence/non-existence assumptions of lines in other corridors.

Map Two shows the individual radial corridors, and Map Three shows the crosstown corridors.

B. Line Screening (Corridor Optimization) Overview

Line screening will be used to determine the optimal line within each corridor. The optimal line will be determined based on a demand per unit cost evaluation criterion, whereby the variable proposed new line in the corridor that has the highest ratio is considered optimal. This line, along with the do-nothing alternative for the corridor,* is input into the macro system-wide planning phase of the evaluation process. Also included in the macro phase are all the constant lines. It should also be noted that in the case where a corridor contains only one variable proposed new line, that line is considered the optimal line within the corridor.

For the basic evaluation criterion, demand is defined in terms of entering passengers in 1975, while cost represents the annual net difference in operating and capital subsidy between the variable proposed new line and the relevant variable existing line. Both the demand and cost variables are described in detail in later sections of the report.

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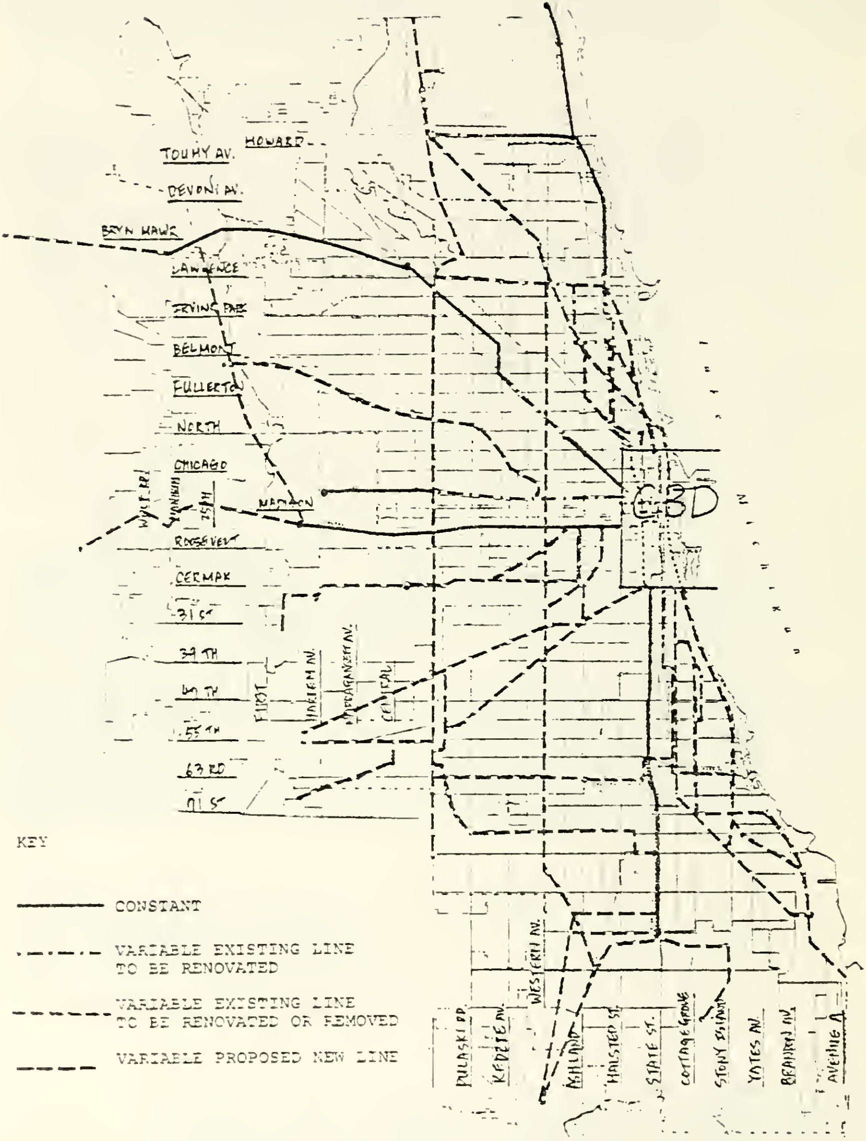
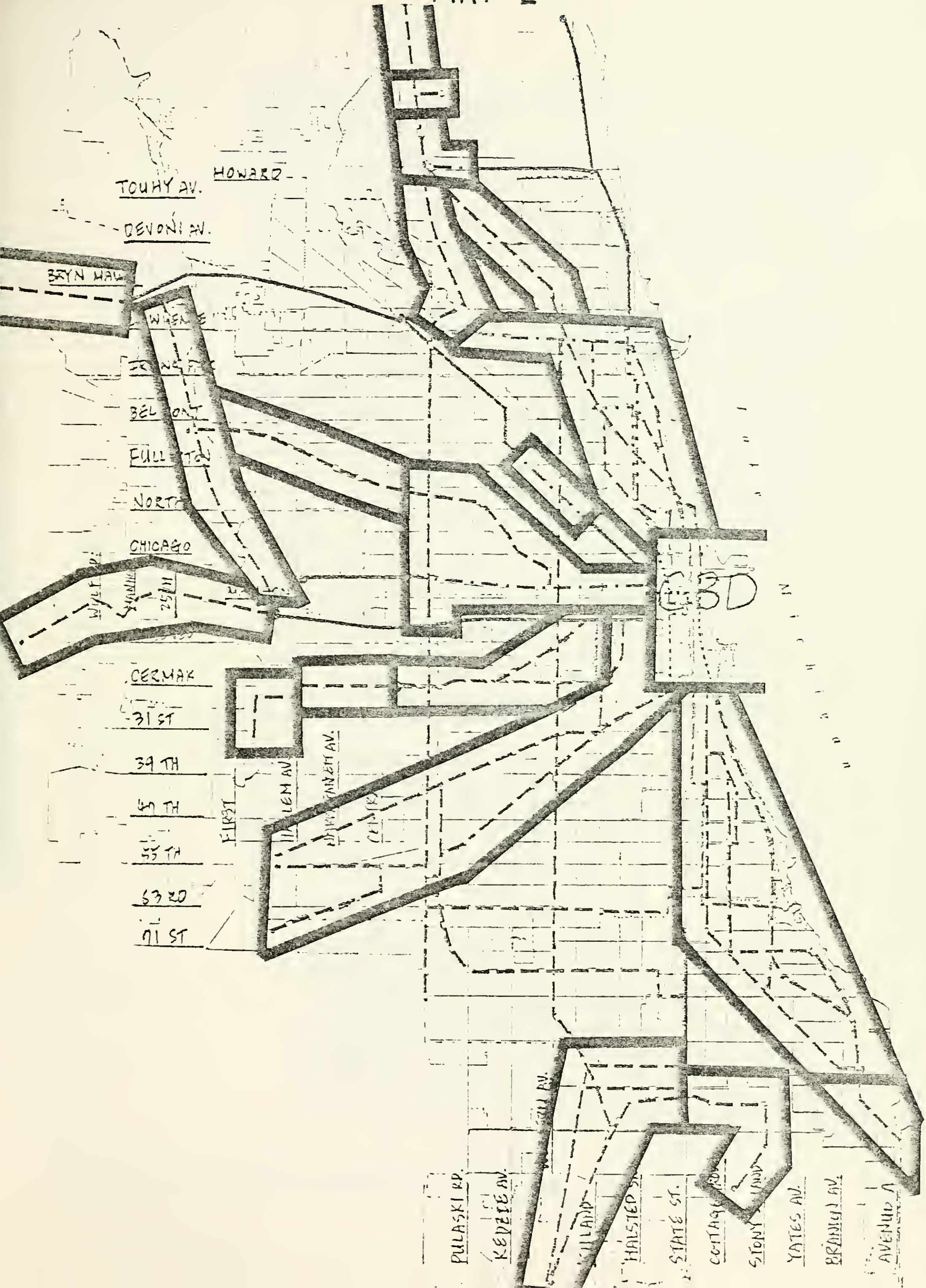
*The do-nothing alternative would be either a variable existing line, or no line at all. Dependent on the specific corridor, the existing line would be classified as either a variable existing line to be renovated, or a variable existing line to be renovated or replaced.

MAP 1


HOWARD
TOUHY AV.
DEVON AV.
BRYN MAWR
LAWRENCE
IRVING PARK
BELMONT
FULLERTON
NORTH
CHICAGO
WOLF RD
MANNHEIM
25TH
MADISON
ROOSEVELT
CERMAK
31 ST
39 TH
47 TH
55 TH
63 RD
71 ST
FIRST
HARLEM AV.
NARRAGANSETT AV.
CENTRAL
CBD
PULASKI RD
KEDZIE AV.
WESTERN AV.
ASHLAND
HALSTED ST.
STATE ST.
COTTAGE GROVE
STONY ISLAND
YATES AV.
BRANDON AV.
AVENUE A
KEY
CONSTANT
VARIABLE EXISTING LINE TO BE RENOVATED
VARIABLE EXISTING LINE TO BE RENOVATED OR REMOVED
VARIABLE PROPOSED NEW LINE

MAP 2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CICERO
CBD
PULASKI RD.
KEDZIE AV.
WESTERN AV.
ASHLAND
HALSTED
STATE ST.
COTTAGE GROVE
STONY ISLAND
YATES AV.
BRANDON AV.
AVENUE

1. Analysis of Application of Corridor Optimization Evaluation Criterion

As with any general sketch planning criterion, the basic drawback in using the corridor optimization evaluation criterion appears to be the loss of information implicit in its application, as well as a possible bias against certain types of alternatives.

With regard to the loss of information, of special significance would be the loss of information with respect to the variance between alternatives among different criteria components, and the complete exclusion of certain other criteria. However, as is explained in detail below, the application of the corridor optimization evaluation criterion within corridors only greatly reduces this potential loss of information. This is basically due to the fact that, excepting demand and cost, all the variable lines within a corridor have a comparable impact on the other evaluation criteria (these include ridership demographics, operational impact, and environmental impact). Thus these criteria can be thought of as constants, and eliminated from the evaluation. Relatedly, the loss of information due to the sub-division of the rail network into commuter and rapid rail is examined below, and is found to be limited. In order to test for possible biases, the evaluation criterion is analyzed with respect to cost, and is found to be acceptable.

For all these reasons, the evaluation criterion based solely on demand and cost is considered to be an adequate evaluation measure. For comparison purposes, it should be noted that UMTA has used a similar criterion, capital cost per new passenger, to evaluate a specific project.*

a. Demand

While demand varies between lines within a corridor, the year for which it is estimated must be predetermined since patronage will vary over the planning period due to changes in population and employment. However, since lines within the same area are similarily impacted by population and employment changes, it is possible to predetermine a year for which demand is estimated without a concurrent loss of information. For purposes of accuracy and ease of analysis, demand will be estimated for 1975.

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* This is the PATH extension to Plainfield, New Jersey.

A related issue is the assumed travel patterns under which demand is estimated. Three alternatives are: (1) fixed trip distribution, which involves estimating new mode splits only; (2) fixed trip generation, which requires estimating new distributions and mode splits; and (3) an entirely unfixed situation which includes estimating new generations, distributions and mode splits. Method one implies that either the impact of a new line on regional accessibility (trip distribution) is minimal or that all new lines within a corridor result in similar changes in regional accessibility. The later implication is acceptable and allows the method to be used. The basic trade-off is between increased theoretical validity (favoring the third method) and increased accuracy and ease of analysis (favoring the first method).

b. Impact on Other Regional Benefit Criteria

i Ridership Demographics

The ridership demographics criterion measures the degree to which a line serves certain sub-groups for which transit service is considered important. It is defined in terms of the number of people within each sub-group that are contained within the service area of the line, where the service area contains either all areas within a set distance of a line, or all areas for which the line provides the minimum transit travel time to the CBD. It is possible that the service areas for different lines may overlap.

Regardless of the exact sub-groups or service area definition used, all lines within a corridor serve these groups to approximately the same extent. Thus, for corridor optimization, little information is lost by not considering this criterion.

ii Operations

The operational criterion measures the

operating efficiency of lines, and includes such things as balanced passenger loadings, sufficient track, terminal and yard capacity, adequate operational flexibility, and minimum junctions.

A basic problem inherent to these measures is that they only have meaning when applied on a system-wide basis, and thus it is impossible to estimate the operational impact of lines independently of each other. A second problem is that while many of these items are dependent on CBD facilities and central area routings, future routings are unknown at the present time. A third point is that many of the operational considerations, such as balanced loadings, can be implemented at a fairly minimal cost; and thus are more of a micro, than macro, problem. Finally, and most importantly, on a regional evaluation level, all lines within a corridor have a similar operational impact.

Thus, for corridor optimization, a minimal amount of information is lost by not considering this criterion. A related factor is that, for the reasons noted above, this criterion may even be impossible to include in the system-wide mathematical programming evaluation.

iii Environment

Of all the regional benefit criteria, the loss of information is greatest with respect to the environmental criteria due to both construction type and alignment. However, even in this case the variance between different alternatives, and thus the information lost, is not that great.

Basically, the environment criterion consists of three measures: regional impact, neighborhood impact and user impact. The major regional impacts are the reduction in air pollution and the conservation of energy due to the reduced number of automobile vehicle-miles. This is a function of diverted automobile trips, which are also reflected in the demand criterion. Internal to a corridor, the relative demand of alternative lines will, in general, reflect the relative numbers of auto-diverted trips; and thus this impact is indirectly addressed in the demand criterion.

The most important neighborhood impacts are noise and aesthetics. The existing elevated, as compared to at-grade or subway facilities, has the most serious negative impacts with respect to both items. However, any new elevated structure would be a "trough design" similar to BART, which would be aesthetically pleasing, and result in little noise pollution. Any new subway facility, by its nature, would have minimal impact. Finally, an at-grade facility would be built on an expressway or railroad right-of-way, and both are surrounded by land uses which, in terms of environmental factors, are compatible with rail transit. The major neighborhood impact would involve removal of existing elevated structures, and this impact is constant for all proposed new lines within a corridor.

The relevant user impacts are also noise and aesthetics. In this case, elevated or at-grade facilities are thought to be somewhat superior to subways in that they are quieter and afford a scenic view; however, the relative importance of these factors to the users has been found to be slight.* For this reason, this impact is deemed insignificant for use as a criterion.

In summary, the alternative proposed new lines within a corridor have a fairly similar environmental impact, and the loss of information with respect to the exclusion of this criterion is not that great.

iv Summary Impact on Regional Benefit Criteria

In conclusion, those component criteria of the regional benefit function other than demand have been found to be either constant over all alternative proposed new lines in a corridor, or indirectly treated in the evaluation criterion. Thus, the loss of information with respect to the exclusion of these criteria has been found to be quite limited.

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*One report which reports this insignificance is: "Toward an Intermodal Hierarchical Model of Attitudinal Indifference, Preference and Choice: A Study of Mass Transportation in Chicago" Peter Strauss, Northwestern University, Evanston, Illinois, 1972.

c. Commuter Rail Impact

A second potential problem is that the classification of the rail network into commuter and rapid rail may result in a loss of information in that the commuter rail lines may have differing impacts on alternative rapid transit lines within a corridor. A corridor-by-corridor analysis was undertaken, and it was found that in only three cases would the existence/non-existence of commuter rail lines have a slightly different impact on alternative proposed new rapid transit lines within a corridor.* Thus this classification results in a minor loss of information only.

d. Cost Implications

A third problem, of a slightly different nature, is that the use of a sketch planning criterion may result in a systematic bias against certain types of alternative new lines. With regard to the corridor optimization evaluation criterion, it is possible that there may be a bias towards the lower cost alternatives since, within a corridor, the relative patronage on the lines is more similar (due to geographically adjacent alignments) than the relative costs (due to the extremely expensive nature of subways).

An analysis of the possibility of this anti-high cost bias was undertaken. This involved calculating the lowest possible total cost for all alternatives included in the system-wide evaluation phase. This was estimated by assuming that the rapid transit minimum cost alternative within each corridor was optimal, and calculating the total cost associated with these alternatives. Added to this total was an estimate of the costs of proposed commuter rail alternatives.

This total was 5.5 billion dollars.** An approximation of the greatest possible amount of funding available for major capital projects in the region was taken to be 150-200 million dollars per annum, which results in a total planning period budget of 3.8 - 5 billion dollars. Thus it will be impossible to construct all the minimum within-corridor cost alternatives prior to the horizon year, and choices between proposed new lines in different corridors will have to be made.

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*It should also be noted that the three commuter rail branches within the City of Chicago are assumed to cease operations if rapid transit extensions are constructed in their area.

**It should be noted that the Central Area project is not included in this analysis, and its associated cost of 1.4 billion is not included in this figure.

Since the construction of all proposed alternatives is not possible, it is fairly safe to assume that, over the planning period, there will be a favoritism towards minimum cost alternatives. Viewed from a slightly different perspective, this implies that the marginal benefit provided by the high cost, as opposed to minimum cost, alternative within any corridor will always be less than the benefit provided by the minimum cost alternative in any other corridor. While this may not be true in all cases, in general it seems to be realistic. Thus the existence of a potential bias can actually be considered as a positive occurence.

e. Summary of Application of Corridor Optimization Evaluation Criteria

In conclusion, it has been found that the use of the corridor optimization evaluation criterion to determine optimal lines within a corridor only limits the potential loss of information inherent in the utilization of sketch planning methods. In addition one potential bias, relating to cost, was found to be an advantage.

C. Treatment of Geographically Adjacent Corridors

Lines in geographically adjacent (or adjoining) corridors are interdependent in that the demand on the lines (and thus the user benefits) in one corridor are impacted by the existence/non-existence of the lines in the other corridor. With regard to sketch planning, the important point concerns the degree to which the lines within a corridor are affected differently by lines in an adjacent corridor. Since an a priori determination of this degree of difference is difficult to make, the alternative lines within each corridor will be examined under varying assumptions of existence for the line in the other corridor. If the same line is optimal under either assumption of existence then it is the optimal line. If different lines are optimal, then the best line within the corridor will be chosen judgmentally, with consideration given to such factors as the extent of the impact of the adjacent corridor line (i.e., the magnitude of that demand relative to the demand of the lines in the specific corridor), and the impact of other criteria which were not considered. Furthermore, the inaccuracies inherent in cost and demand estimation will be closely checked.

III. DETAILED METHODOLOGY APPLICATION

The final section of the paper is a detailed explanation of the two components of the corridor evaluation criterion.

A. Demand

Given that the reasoning behind the estimation of demand for a predetermined year has been presented, there are two other points which should be discussed: the conditions under which demand is estimated (i.e., the existence/non-existence assumptions for specific lines), and the validity of using entering passengers as the measure of demand.

Based on both line classification and corridor definition, the existence/non-existence assumptions for the estimation of demand are fairly straight-forward. For all corridors, a base system, consisting of constant lines and CBD lines, is assumed to be in existence. Since it turns out that within corridor optimal lines must only be determined for those corridors which are connected to the base system, demand for each variable proposed new lines is estimated assuming only that the base system and the proposed line is in existence.

Prior to the exact specification of the demand criterion, various measures were considered including: total boarding passengers, total passenger miles, new passengers, total travel time savings, and average travel time per rider. The total passenger mile measure was eliminated since: (1) it is biased toward indirect and longer lines; (2) it favors lines which better serve outlying, as opposed to intermediate, areas (i.e., have heavy terminal loadings); and (3) it does not differentiate between a small number of long trips and a large number of short trips. The average travel time per rider criterion was not used since it is insensitive to the actual number of riders.

The three remaining criteria were considered somewhat better. The new passengers criterion has the advantage of being oriented towards the actual measurement of regional benefit, but has liability of being sensitive to only a sub-segment of total demand. The total travel time savings is also oriented towards regional benefit measurement, but has the same liability as passenger miles in that it does not differentiate between a small number of trips with great savings and a large number of trips with small savings, and is also somewhat unconventional. The total boarding passengers criterion is sensitive to all components of demand, is directly related to revenue measures, and is simple, but does not directly measure regional benefits. The positive aspects of this measure outweigh the negative one, and thus it is recommended for use.

B. Cost

The cost criterion includes operating cost, capital cost, and revenue impacts; and is defined as the difference between the annual subsidy of a proposed new line and the annual subsidy required to keep those variable existing lines which would be replaced in operation to the planning horizon.* For those corridors where the proposed new line would not result in the replacement of existing lines, the replacement costs are zero. All costs are in 1975 dollars.

The basic form of the cost criterion is: (proposed new line amortized annual capital cost plus proposed new line annual operating cost minus proposed new line annual revenue) minus (replacement existing plus replacement line amortized capital cost plus replacement line annual operating cost minus replacement existing line annual revenue.)**

Capital costs will be amortized with respect to the life of the project and the horizon year, and will be expressed in annual terms. Amortized annual capital cost is defined as the product of: the total capital cost of the project, the percentage of the project life which is concurrent with the planning period, and the inverse of the number of years of project life which are concurrent with the planning period.

It is assumed that the capital cost of all new lines occur in 1975, and all replacement costs occur when they are scheduled. As an example: a new line with a capital cost of $50,000,000 and a project life of 50 years, would have an amortized capital cost equal to $1,000,000((50,000,000 x (25/50) x (1/25)).

Finally it should be noted that the expression of costs in terms of net present value was considered. However, it is impossible to calculate an accurate net present value for the capital and operating costs of the proposed new lines since the date of their completion is unknown (and is a major output of the macro-system-wide evaluation phase). Thus, costs are not presented in terms of net present value.

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*It has been assumed that the construction of new rapid transit lines will result in changes only for existing line haul services, which include rapid transit, commuter rail and express bus. It is realized that local bus services would be altered to better serve new line-haul transit services, but the cost of this change is minimal in comparison to the cost of major changes in line-haul services.

** Details of each cost component are described in "Capital and Operating Costs for the Replacement and Expansion of the Chicago Rapid Transit System," RTA Technical Report, TR-75-02